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Incense, sparklers and cigarettes are significant contributors to indoor benzene and particle levels

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Abstract
Introduction. The increased use of incense, magic candles and other flameless products often produces indoor pollutants that may represent a health risk for humans. Today, in fact, incense and air fresheners are used inside homes as well as in public places including stores, shopping malls and places of worship. As a source of indoor contamination, the impact of smoke, incense and sparklers on human health cannot be ignored.
Aim. In the present work, we report the results of an emission study regarding particles (PM10 and particle number concentration, PNC) and benzene, produced by various incense sticks and sparklers.
Results and discussion.The results obtained for benzene, PM10 and PNC, showed a strong negative influence on air quality when these products were used indoors. Various incense sticks gave completely different benzene results: from a small increase of the benzene concentration in the air, just slightly above the background levels of ambient air, to very high concentrations, of more than 200 µg/m^3 of benzene in the test room after the incense sticks had been tested.

Key words
- incense
- PM10
- benzene
- on-line mass spectrometry
- indoor air quality

INTRODUCTION

Indoor air quality (IAQ) has become a very important issue in recent years. In developed countries, people spend more than 90% of their time indoors either in the working place, in public or private transportation, at home, at school and even during their free time. So the exposure to contaminants present in indoor air is a topic that, over recent years, has attracted ever more interest [1, 2]. Indoor air pollution, resulting from specific indoor activities such as cooking or smoking cigarettes, has been characterized [3, 4] but incense emissions must also be considered as a source of indoor air pollutants. In a poorly ventilated area, such as the home, it is hypothesized that smoke emitted from incense could result in high concentrations of harmful chemical pollutants [5]. Incense burning was found to be the significant source of large amounts of particulates, heavy metals, polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs) [6, 7, 8-12]. The presence of smokers has an important direct effect on air quality and on people's exposure to contaminants [13]. Incense sticks are first lit, then fanned out, and continue to smolder without a flame, releasing their fragrance compounds. People use them in their homes to produce a pleasant smell or to mask odors, to aromatize the home environment, and/or as a calming mixture to ease the stress of the day. Some people are convinced that these sticks purify indoor spaces. In Ancient Egypt, for example, incense smoke was considered as a medicine and used for healing practices [14]. Unfortunately, some incense releases "healthy" ingredients as well as some very dangerous substances at concentrations that can cause adverse health effects [15, 16]. Recently, more studies have focused on the effect of these substances which these products release although people believe that they improve indoor air quality [17, 18, 19-23]. On the basis of these studies, the European Community has adopted the report *Emission of chemicals by air fresheners* [24]. In our work, we analysed the influence of incense sticks, sparklers and cigarettes on indoor air quality and gave particular attention to two classes of pollutants of broad public concern: particles and benzene. Benzene, like benzo(a)pyrene (BaP), one of the most toxic PAHs, is classified as a human carcinogen and causes genotoxic effects [16]. For particles, we also report the obtained particle size distribution. Pollutants of an indoor source, like cooking stove, are mostly bound on the fine dust fraction (≤ 2 µm in size) and also a large amount of the PAHs (> 75%) belongs to this fraction only [25].

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MATERIALS AND METHODS

Measurements were performed in a room with a volume of 75 m^3. Before sampling, the windows were opened to allow outdoor air to enter, then measurements began. Several different kinds of incense sticks were tested and several test runs were performed for every kind of incense. Sticks from the same packet often varied considerably in thickness and weight and, so, to improve the repeatability of the tests, two sticks (or two sparklers) were lit. We did not perform different experiments with single sticks and mediate the measurement results. The reported measurement results are the time course of the concentration we obtained in the indoor air, when two sticks or two sparklers were lit together. A person smoked two cigarettes in the room and the results were compared with the incense emission test runs. The average temperature of the room was 26 °C and the relative humidity was 60%. Incense sticks and sparklers were put on a working bench in a way that the emissions started at 1 m above ground level and placed in the middle of the room. The measurement equipment was placed on a bench at 1 m distance from the wall, in the same position where usually a person is working, sampling 1 m above the floor and 1.5 m in horizontal distance from the emission source. After the incense was lit, the room remained closed until the end of the test. The time interval for conducting the experiments was given be the time incense sticks or sparklers needed to burn completely. Incense normally smoldered for approximately one hour. The natural air exchange rate of the room under testing conditions, with closed doors and windows in order to get bad ventilation testing conditions, was below 0.2 h^{-1}.

Particle measurements

An aerosol spectrometer made by Grimm, model 1.108 was used to detect particles. Particles are measured by the physical principle of orthogonal light scattering. The spectrometer makes it possible to determine the number of particles as well as the particle mass. The aerosol spectrometer classifies the particle size in 15 different size channels from 0.25 to 20 µm. A scanning mobility particle sizer (SMPS) system (Buonanno *et al.*, 2013), consisting of a butanol-condensation particle counter (CPC) from Grimm, model CPC 5403, (www.grimm-aerosol.com) coupled with a Vienna-type differential mobility analyzer (DMA) 55706 operating in a range from 5.5 and 350 nm, was used to detect the particle number concentration (PNC).

Benzene measurements

An on-line mass-spectrometer from V&F (Airsense compact, www.vandf.com) based on the ion-molecule reaction (IMR-MS) was used for benzene measurements [26, 27]. This instrument uses electron ionization to create a primary ion beam of mercury (Hg), xenon (Xe), or krypton (Kr) producing ions with different ionization potential of 10.4, 12.2 and 13.9 eV, respectively. The primary ion beam collides with the neutral sample gases resulting in charge exchange when the sample molecule has a lower ionization potential. Selected ionization of desired gas molecules can be achieved by tailoring primary ionization gases with higher ionization energy level which provides ultra-trace (ppb) detection for selected compounds (for example benzene) in the presence of bulk amounts of atmospheric gases like O_2, N_2 and CO_2. Interferences on the selected masses are important factors when approaching on-line MS measurements. The Airsense IRM-MS instrument, commonly used in the automotive sector to analyze engine emissions, is optimized to minimize such interferences in combustion exhaust fumes. This instrument generates a measurement result in less than one second and enables us to trace the variation of the benzene concentration in the ambient air continuously from the moment the incense stick was lit. The whole exposure cycle, from the moment the stick was lit until the end of burning when maximum concentration is reached, can be traced. Traditional benzene determination techniques rely on the use of sorbents in trapping VOCs in air for subsequent analysis by desorption and instrumental determination. The sampling time is dependent on the instrumental configuration of the system and can vary from minutes in the case of an on-line trapping and on-line desorption coupled to a GC-FID instrument, to hours, in the case of a standard trapping and solvent desorption, and several weeks in the case of passive sampler [28]. Using an on-line mass spectrometer, a single measurement result is available in less than a second. On-line measurements also enable us to trace pollutants in the indoor environment under dynamic, realistic (real live) conditions – for example when people are moving around. The effect of opening a door or a window can also be measured directly. One disadvantage of these rapid measurements is the relatively broad variation of the results, (see chapter "Results and discussion") as an unsteady, tottering evolution of the concentration during the experiment. So, instead of using average values based on a larger time interval, such as several seconds or minutes, we decided to use the 98th percentile to define the maximum concentration, in order to keep the original data as much as possible. We performed a calibration control on the instrument with standardized gas mixtures before and after the test runs.

RESULTS AND DISCUSSION

Particle results

Background concentration. In order to evaluate the specific increase of particle pollution of the indoor environment caused by incense, sparklers and smoke, a series of measurements was started in order to define the background level. We found an average background concentration of 6 µg/m^3 for the PM10 and PNC of 18 500 p/cm^3 in the room. A significant increase of benzene and particles was observed as the combustion of incense, sparklers and cigarettes proceeded.

Results of the combustion test. The measurement results are resumed in *Table 1*. Compared to the background concentration, we found an increase of the particle mass on a PM10 basis of nearly two orders of magnitude. There was an increase from 6 µg/m^3 found in ambient air before we started with the test to 244 µg/m^3 after two cigarettes had been smoked. The combustion of various

Table 1
Particle and benzene measurement results

Source	Particle number concentration PNC (p/cm³)	PM10 (μg/m³)	Benzene 98th percentile (μg/m³)
Ambient air	18 500	6	5
Incense 1, vanilla	173 700	342	42
Incense 2, cedar	144 000	247	53
Incense 3, incense	126 600	339	205
Incense 4, cinnamon	138 100	211	12
Sparkler	114 800	298	79
Cigarette smoke	116 500	244	18

incenses, incense 1 with vanilla, incense 2 with cedar, incense 3 with cinnamon and incense 4 with incense flavor, showed concentrations of PM10 ranging between 247 μg/m³ for the cedar incense and 342 μg/m³ for the vanilla incense. The concentration of PM10 after the ignition of the sparklers was found to be 298 μg/m³.

The total particle number increased by a factor close to ten compared to the background level of ambient air we typically find in an urbanized, road traffic influenced area. The smoke of two cigarettes increased the PNC to 116 500 p/cm³. Incense sticks ranged between 124 600 p/cm³ for incense with incense flavor and 173 700 p/cm³ for vanilla incense. Ignition of the sparklers resulted in an indoor air concentration of 114 800 p/cm³. The particle size distribution we obtained in the indoor air when incense stick 2, sparklers and cigarettes were lit, is resumed in *Figure 1*. Independently from the source, we obtained a nearly monodispers particle number distribution, typical for combustion sources [21] showing a main mode around 100 nm.

In general, independent of the particle dimension, we registered an increase of the particle concentration. If we consider only the very small particles (< 10 nm), however, we find even higher levels in the ambient air before lightning sticks or sparklers. The small particles present in ambient air can be removed by aggregation to bigger aerosol particles released by burning incense. This process leads to a change in the aerosol particle-size distribution. Incense burning emits particles with a relatively close size distribution, the mean particle diameter being close to 100 nm. Cigarette smoke leads to a wider particle size distribution, while sparklers are somehow between. The mean diameter in all three cases was between 60 and 100 nm and the resulting PM10 load in the indoor air was considerably higher that the action value/limits proposed in guidelines (rapid action value for PM10 75 μg/m³ and 15 μg/m³ annual mean [29] and 20 μg/m³ on an annual mean and 50 μg/m³ on an 24-hour mean basis for PM10 in *WHO Air quality guidelines* (AQGs) [30].

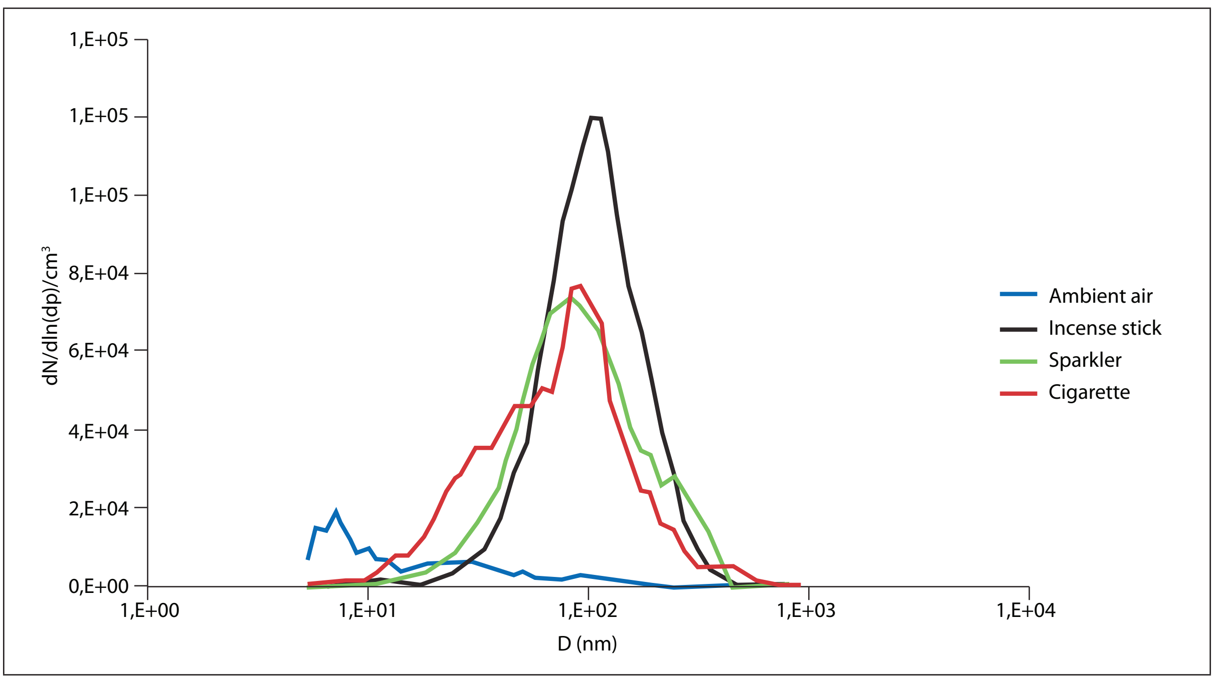

Figure 1
Particle size distribution in ambient air after incense stick 2, sparklers and cigarettes were lit.

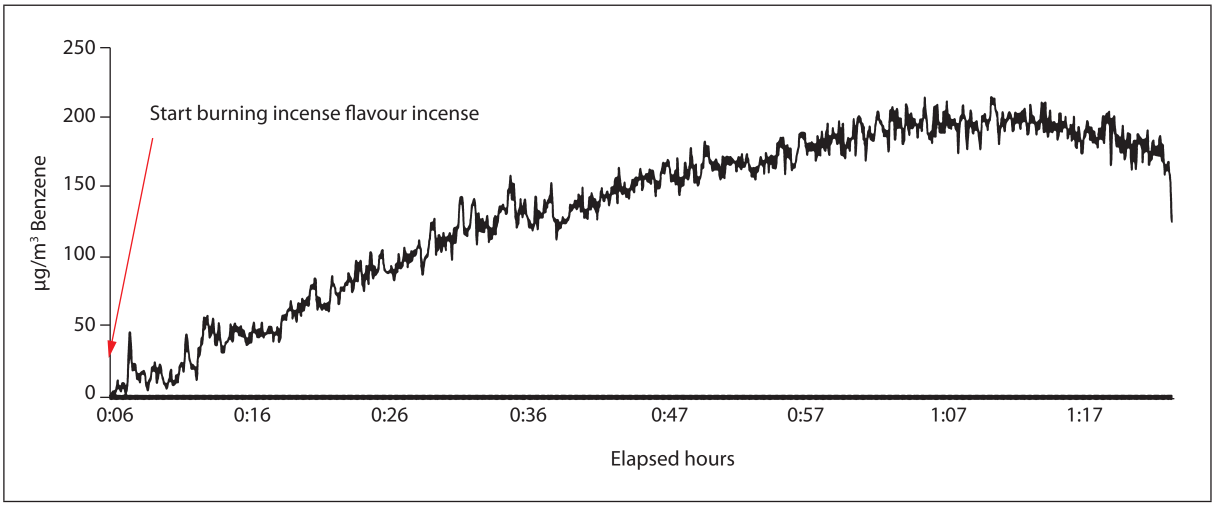

Figure 2
Time trend of the benzene concentration produced by burning incense flavor incense.

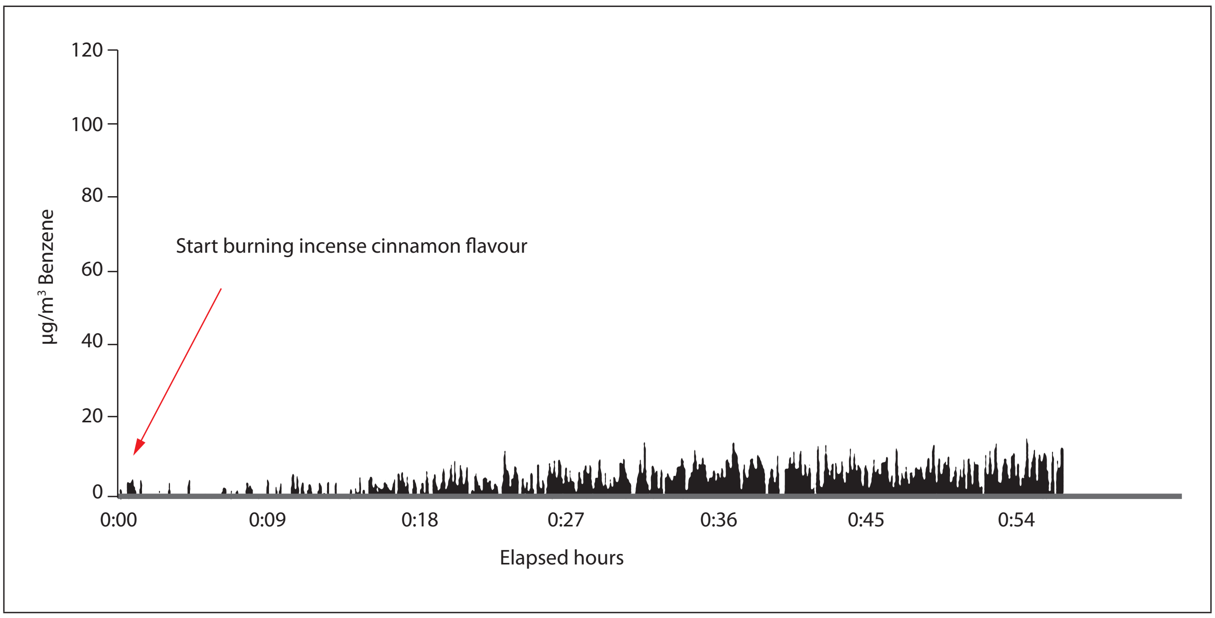

Figure 3
Time trend of the benzene concentration produced by burning cinnamon flavor incense.

Benzene measurement results

Background concentration. During our tests, benzene was already present in the outdoor air at background levels at a concentration of 2 to 5 µg/m³.

Results of the combustion test. The burning of various types of incenses leads to different maximal benzene indoor concentrations. As reported in *Table 1*, we found values from 12 to 205 µg/m³ (always expressed as 98th percentile values) in the indoor air after burning incense. The use of an on-line measurement system enabled us to trace the time trend of the benzene concentration in air. As reported in *Figures 2, 3 and 4*, no average concentration was determined but, rather, the evolution of the concentration from when burning started can be monitored. In *Figure 2,* related to incense 1 (incense flavor), we observed an increase of the benzene concentration from background levels to a remarkable concentration of approximately 205 µg/m³. Not all incense sticks produce such high, dangerous benzene concentrations. In *Figure 3*, incense 2 (cinnamon flavor) showed only a slight increase from background levels after burning for one hour and an end concentration of 12 µg/m³ was observed. In *Figure 4*, the time trend after burning incense stick 3 (cedar flavor) is visible in the first part. Then, we observed how the benzene concentration went down to background levels after we opened the windows and ventilated the room. In the second part of *Figure 4*, we observed how the benzene concentration rose again, starting from background level, when a sparkler was lit in the room with closed windows.

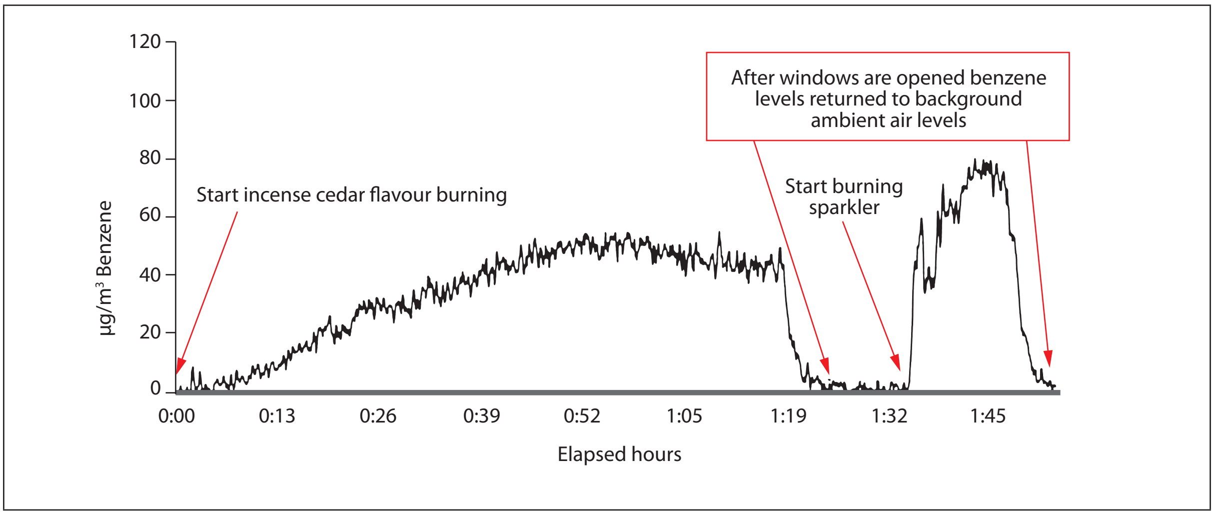

Figure 4
Time trend of the benzene concentration observed after burning cedar flavor incense, then changing the air by opening the windows and afterwards burning a sparkler.

CONCLUSIONS

Incense, cigarettes and sparklers, once lit, produce considerable indoor air particle pollution. Regardless of which of them is lit, the resulting PNC is around 100 000 to 200 000 particles per cm^3 at the end and, on a PM10 basis, we found from 200 to 300 $\mu g/m^3$. Regarding benzene emissions, a quite different picture resulted. Various incense sticks gave completely different results. One caused a small increase of the benzene concentration in the air, just slightly above background levels of ambient air, whereas another produced a considerable concentration of more than 200 $\mu g/m^3$ of benzene in the test room. The proposed method of on-line measurement of the benzene concentration enabled us to track how the emissions influence the indoor air quality in a simple, fast way. By applying this technique, several different incense sticks were tested in one working day and the results were immediately available. Since various incense sticks gave a completely different indoor benzene concentration, the proposed on-line mass spectrometric method helped to quickly identify those which are potentially harmful.

Efforts in order to promote a greater public awareness of this kind of indoor pollution should be addressed. The setting up of proper information campaigns, putting in evidence the possible risks related to the use of these products, should help prevent negative health effects.

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Conflict of interest statement

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